WIREWORMS

ffecting the agricultural crops of Maine

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nd sifting for a count of wireworms in a nple of soil. A machine sifter to do the rk on a larger scale is shown on page 24.

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SUMMARY

Wireworms annually cause a loss of thousands of dollars to agricultural crops in Maine. Wireworms are the young or larvae of elaterid beetles known as "skipjacks" or "click-beetles." The life stages are egg, wireworm or larva, pupa, and adult.

There is a long list of plants upon which wireworms are known to thrive. They injure crops by feeding on the underground parts of plants. Occasionally, they may invade and live in the lower portions of the stems of plants. Potatoes are probably more severely injured by wireworms than any other crop in Maine, but corn, grass, ornamentals, and many vegetable crops are also injured.

Wireworms are distributed over almost all of the farming area of the United States and are prevalent in many other parts of the world. They infest a large section of the farming area of Maine, but are relatively less abundant in the potato growing areas of northern Aroostook county than elsewhere.

The length of time wireworms live in the soil varies according to the species present. Consequently, it is a good plan to learn something about the species present and their abundance before risking a susceptible crop on infested land.

A number of alternative methods of control are available today which are of aid in preventing wireworm injury. Cultural practices that destroy grasses and weeds reduce populations to low levels and effectively prevent populations from building up. Crops also vary considerably in their degree of susceptibility to wireworm injury. It is now practical to make use of insecticides for immediate reduction of wireworm populations when necessary.

Heptachlor, aldrin, chlordane, and dieldrin are chlorinated hydrocarbon materials which may be used effectively to control wireworms. Aldrin, chlordane, and heptachlor are readily available, low in cost, and reliable for practical use in wireworm control. Aldrin or heptachlor is used at a rate of 2.5 or 3 pounds of active material per acre. The amount of chlordane found to be effective in wireworm control varies from 5 to 10 pounds of active material per acre.

Dusts containing chlordane have not generally proven as effective as emulsifiable concentrates or wettable powder formulations used with water. Chlordane, aldrin, or heptachlor when used in combination with fertilizers has not generally proven quite as effective as emulsifiable concentrates or wettable powders used as water sprays.

Prompt coverage of the insecticide with soil is necessary to obtain maximum wireworm control. Dusts or water sprays containing these insecticides may be conveniently covered by harrowing. In small plots, a garden rake is effective for mixing the insecticide with the soil. The insecticide is worked in to a depth of 5 or 6 inches. Potato planters with disks or hoes for covering the row are of some help in mixing the insecticide with the soil after the preliminary harrowing.

Flavor evaluations of stored, baked Kennebec potatoes and newly harvested, baked Green Mountain potatoes showed that none of the insecticides tested imparted off-flavor to the baked potatoes. In terms of pounds per acre of active material these tests included 2.5 and 3 pounds of aldrin per acre, 2.5 pounds of heptachlor or dieldrin, 8 and 10 pounds of chlordane, 10 pounds of DDT, and 28 pounds of magnesium sulphate.

> *Warning:* The insecticides used in wireworm control are all toxic to humans and to animals. Therefore the insecticides and their containers should be handled carefully and stored beyond reach of children or others who might mistake the contents.

There is also danger of using excessive dosages of such chlorinated hydrocarbons as aldrin, chlordane, heptachlor, and others. This might involve excessive residues of these poisons in the soil or cause contamination of crops grown later in treated soils. Consequently, the manufacturer's directions should be followed as closely as possible.

BULLETIN 578

WIREWORMS AFFECTING THE AGRICULTURAL CROPS OF MAINE

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Introduction

More than fifty years ago wireworms were destructive to Maine agricultural crops as has been recorded by Patch (1905) and Johannsen and Patch (1911).[2] In the years immediately preceding 1926, wireworms were so destructive that a project on wireworm control was established by the Maine Agricultural Experiment Station. Early results obtained from the experiments conducted under this project were published in 1936 as Bulletin 381, "The Bionomics and Control of Wireworms in Maine." Since this time, promising soil insecticides have been developed. The results of experiments concerning the use of these insecticides and also the general biology of wireworms are discussed in this publication.

Losses caused by wireworms to the agricultural crops of Maine annually amount to thousands of dollars. Potatoes inspected in Maine during 1930 suffered an estimated loss of nearly $384,000, and this figure included only a portion of the northern Maine crop for the year.[3] Consequently, actual monetary losses for 1930 were greater than the $384,000 indicated. Since present grading standards of potatoes are very exacting, excessive wireworm injuries to the tubers will prove costly to potato growers.

What Are Wireworms?

Wireworms are the young or larvae of beetles belonging to the family Elateridae. Wireworm adults or beetles are commonly called "click-beetles" or "skipjacks." Wireworms or larval elaterids live beneath the surface of the soil and consequently are not suspected of much of the injury which they cause to growing plants, roots, and tubers.

Millipedes Are Sometimes Called Wireworms

Millipedes are sometimes called wireworms but differ in that millipedes have many pairs of slender legs located on the body segments

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[2] Literature citations are listed on page 40.

[3] Based on figures furnished by C. H. White, former Chief, Div. of Markets, State Department of Agriculture, Augusta, Maine.

from the front to the rear of the body. Millipedes are usually black or grayish-black in color. Millipedes characteristically curl up into a loose spiral position when disturbed (fig. 1). On the other hand, while they can bend their bodies, wireworms do not curl up in a spiral position as millipedes do.

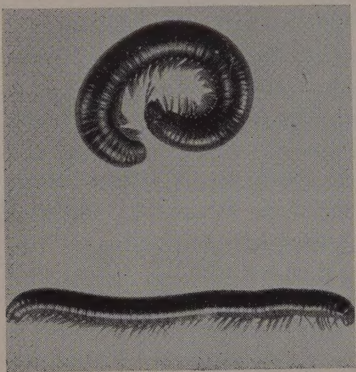

FIGURE 1. Millipedes shown at left are often mistaken for wireworms, but wireworms do not curl up in this characteristic spiral position when disturbed. Also wireworms have but three pairs of legs positioned well forward on their bodies in contrast to the many slender legs of millipedes.

Injurious Wireworm Species

Less than a dozen species of wireworms are responsible for the larger share of the losses caused by wireworms to Maine crops. These include the wheat wireworm, *Agriotes mancus* (Say); the so-called corn wireworm belonging to the genus *Melanotus;* a group belonging to the genus *Ctenicera*; two species belonging to the genus *Hemicrepidius*; and the smallest common destructive species, *Hypolithus abbreviatus* (Say), referred to here as the abbreviated wireworm because of its small size. The known distribution of the more important species is presented in figure 2. A list of the various species of wireworms found in Maine is given on page 38.

Identification of Wireworms

A working knowledge of how to identify injurious species of wireworms is important because the species vary in the length of time which they can be expected to remain in the soil. The form and structural characters of the last or anal segment of the body are useful in the identification of wireworms. The wheat wireworm is rather easily identified by its cylindrical form, the two eye-like spots on the ninth or posterior body segment (fig. 3), and by its bright yellow color. A hand lens of low magnification helps in observing structural characters. Larvae of the genus *Melanotus,* to which the so-called corn wireworm belongs, are identified likewise on the basis of their cylindrical form and

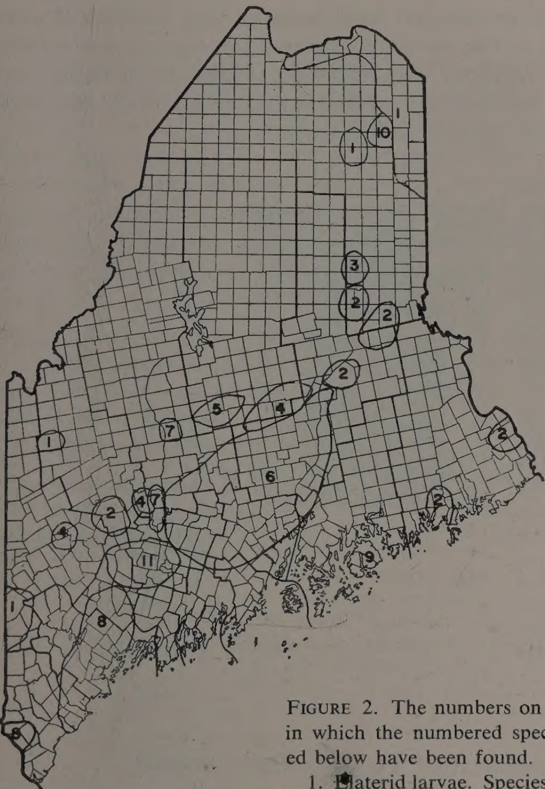

FIGURE 2. The numbers on the map indicate areas in which the numbered species of wireworms listed below have been found.

1. Elaterid larvae. Species undetermined
2. *Agriotes mancus* (Say)
3. *Agriotes mancus* and *Hypolithus abbreviatus* (Say)
4. *Limonius* sp. and *Melanotus* sp.
5. *Agriotes mancus, Ctenicera* sp. and *Limonius* sp.
6. *Agriotes mancus, Melanotus* sp. and *Limonius* sp.
7. *Melanotus* sp.
8. *Melanotus* sp. and *Agriotes mancus*
9. Species recorded by Johnson 1927, pp. 100-102.
10. *Ctenicera cylindriformis* (Hbst.)
11. *Agriotes mancus, Ctenicera cylindriformis, Hypolithus abbreviatus, Melanotus* spp., *Oestodes* sp., *Cardiophorus* spp., and larvae of the subtribe *Adrastina*

the shape of the anal or posterior body segment (fig. 4). Except when newly moulted, corn wireworms have a definite mahogany red or reddish brown cast. Other injurious wireworms of Maine are somewhat less cylindrical in form in that they are flattened dorso-ventrally and have horn-like structures on the last body segment (fig. 5).

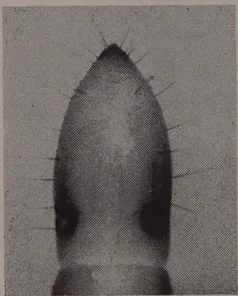

Figure 3. The anal segment of *Agriotes mancus* (Say), or wheat wireworm which is identified by the two eye-like spots on its posterior body segment and by its bright yellow color.

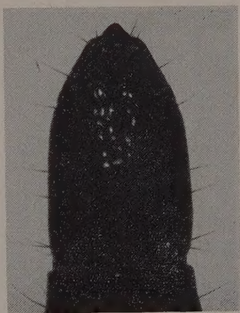

Figure 4. Anal segment of *Melanotus* or corn wireworm which is like the wheat wireworm in its cylindrical form but is a definite mahogany red or reddish-brown in color.

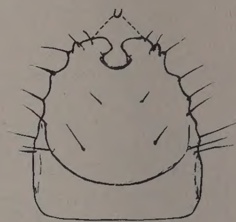

Figure 5. The anal segment of *Ctenicera cylindriformis* is less cylindrical in form, flattened dorso-ventrally, and has upon it horn-like structures known technically as urogomphi.

Wireworm Host Plants—Maine Record

Wireworms have been observed feeding upon 49 different plant species in Maine. Some of these wireworm hosts are of little consequence to agriculture, but even weeds which support wireworms may favor a build-up of populations injurious to crops that may be planted later in the area. The food plants of the wireworm larvae in Maine are listed on page 38.

Among the weeds which are often infested by wireworms are the grasses such as the so-called "quack grass" or "witch grass" (*Agropyron repens* (L.), barnyard grass, and foxtail grass. Likewise, kale, wild radish, and wild rutabaga are often heavily infested by wireworms, even when growing in cultivated fields. Consequently, weed control has a direct bearing on wireworm control.

General observations show that if witch grass is allowed to grow in cultivated fields it is possible for wireworms to continue to multiply and live there as long as it persists.

Garden and Field Crops Injured by Wireworms

Potatoes and corn are extensively injured annually, while excessive injury occurs occasionally to cabbage plants, beets, spinach, and tomato plants. Beans and peas are usually less severely injured than other crops. Injury is also caused to flowers and many other plants cultivated as ornamentals. The growing bulbs, roots, and stems of gladiolus are especially subject to injury by wireworms. All members of the grass family grown in Maine are subject to wireworm attack, and an immeasurable amount of damage is done to hay and pasture grasses. The roots of the cole crops such as cabbage, cauliflower, broccoli, and rutabaga are all subject to wireworm injury as are many other vegetable crops.

All varieties of beans grown in Maine, including snap beans, yellow eye, and other varieties of field or dry beans will produce crops where wireworm populations would be too great to risk potato production. Corn has been known to withstand the attack of wireworms when infestation levels were as high as 48,000 individuals per acre. From 26 to 100 per cent of the potato tubers were injured by wireworm populations ranging from 42,000 to 532,000 per acre.

TABLE 1

Relation of Spring Wireworm Populations to the Percentage of Tubers Injured

Percentage of tubers injured	Number of plots sampled with wireworm population per acre of:		
	0-14,700	14,800-42,100	42,200-532,000
0-5	49	1	—
6-10	8	5	—
11-25	18	14	—
26-50	8	15	8
51-75	—	5	14
76-85	—	1	13
86-95	—	2	20
96-100	—	—	49
Total number of plots	83	43	104

These data were obtained over a period of several years.

Reduction in Wireworms Decreases Tuber Injury

During the years 1951, '52, '53, and '57, data were taken from treated and untreated plots in order to relate the effect of the spring wireworm population to the percentage of potato tubers harvested which were rejected from U. S. No. 1 grade because of wireworm injury.

The data contained in table 2 were obtained in separate areas. The table is a summary of the per cent of potato tubers rejected because of wireworm injury based on the number of larvae per square foot. It

TABLE 2

Average Percentage of Potatoes Injured by Wireworms

Year	Number of wireworms per square foot		Per cent tubers rejected as U.S. No. 1	
	Treatment	Control	Treatment	Control
1951	0.93	1.90	13.6	45.0
1952	3.95	9.49	11.2	56.0
1953	2.66	6.36	8.2	45.2
1957	0.46	2.30	4.8	39.7

is readily seen that the amount of injury varies greatly and is not consistent with the increase in wireworm population. However, the stage of larval development is of considerable importance since the majority of damage is caused by the larger larvae. The data in table 2 support other data previously obtained which indicate that when one or more wireworms per square foot are present, injury is likely to be greater than is consistent with economic potato production.

How Wireworms Injure Crops

Potatoes are injured by wireworms both directly and indirectly after the tubers set on the vines. A common type of injury is that in which the wireworm burrows into a tuber, sometimes going almost straight in so that the injury cannot be peeled off without causing excessive waste (fig. 6). Another type of injury is more shallow and extensive and a considerable portion of the surface of the potato is eaten

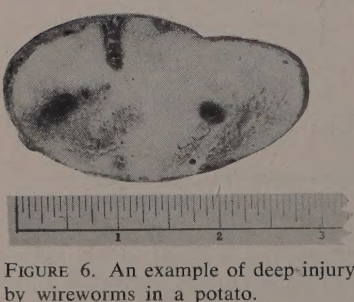

FIGURE 6. An example of deep injury by wireworms in a potato.

FIGURE 7. This wireworm injury is shallow but extensive on the tuber surface.

away (fig. 7). Sometimes wireworms injure the potato tubers when they are beginning to develop or are only partly grown. Such injury is likely to cause deformations which result in their rejection as tubers of U. S. No. 1 grade (fig. 8). Another type of tuber damage is that caused by black scurf fungus (*Rhizoctonia solani* Kuehn) which often enters the tubers in areas that have been attacked by wireworms. In such cases, however, it is often difficult to determine the cause. Figure 9 shows an injured tuber in which *Rhizoctonia* was the only agent involved. The damage resembles certain types of wireworm injury, especially where *Rhizoctonia* has infected the wireworm burrows.

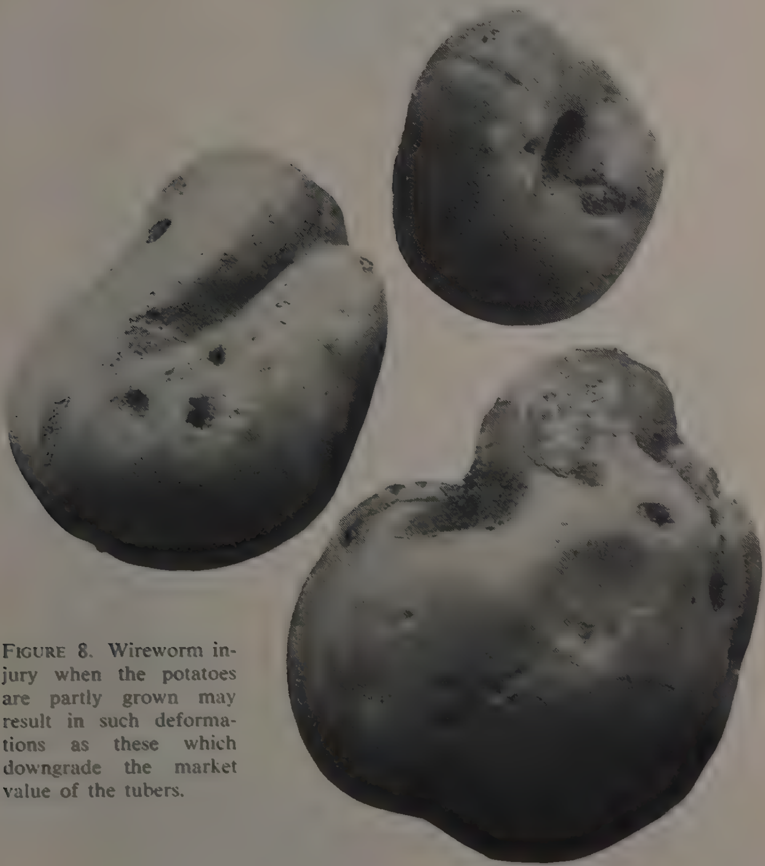

Figure 8. Wireworm injury when the potatoes are partly grown may result in such deformations as these which downgrade the market value of the tubers.

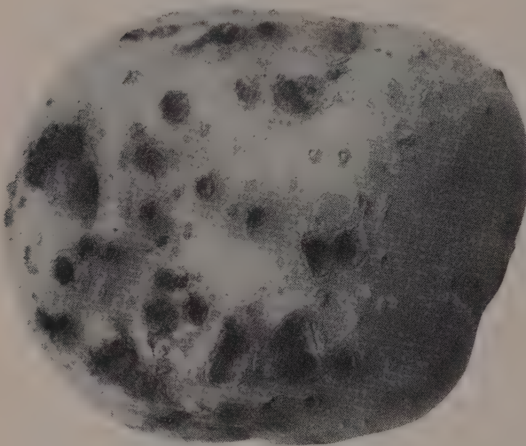

FIGURE 9. *Rhizoctonia* alone was responsible for the looks of this potato, but the damage resembles certain types of wireworm injury in which *Rhizoctonia* has infected the wireworm burrows.

Wireworm injury to planted potato seed is not uncommon. The eastern field wireworm, *Limonius agonus* (Say), is especially destructive to potato seed planted in the sandy soil of the river valleys of Maine. The wireworm species known as the abbreviated wireworm (*Hypolithus*

FIGURE 10. Wireworm injury to potato plants is often overlooked unless the damage is great enough to cause plants to be stunted or to wilt. The root systems of these plants have been seriously injured.

abbreviatus), the so-called corn wireworm (*Melanotus* sp.), and the wheat wireworm have also been found feeding in planted potato seed. Wireworms are often associated with organisms of decay which cause destruction of potato seed in the soil.

Wireworm injury to potato plants is often overlooked unless it is so serious as to cause stunting or wilting of the potato shoots and the destruction of their roots (fig. 10). Such injury may be so extensive as to cause eventual destruction of part or all of the planting, or it may be confined only to parts of the field. Wireworm injury to potatoes continues throughout the entire season.

Von Hegyi (1910) found wireworms to be associated with the blackleg disease of potatoes in Germany.

Wireworm injury to corn is much more common than is generally recognized. As soon as the seed is planted in the soil it is subject to injury by wireworms of all our common injurious species. The growing point or plumule may be injured so that no plantlet is formed. Wireworms sometimes cause total destruction of the seed and are often associated with seed-corn decay (fig. 11). The roots of corn and underground portions of the stalk may also be injured (fig. 12). As soon as the wireworms have destroyed one corn plant they move to another and continue this work during the summer until corn plants over a large portion of the field are destroyed (fig. 13).

Soil Type and Moisture in Relation to Wireworm Habitation

There are several species of wireworms occasionally associated with the wheat wireworm in its relatively heavy, moist soil habitat. These include two species of the genus *Ctenicera,* two species of the genus *Melanotus, Hemicrepidius decoloratus* (Say), and the abbreviated wireworm, *Hypolithus abbreviatus.* Ordinarily these wireworms are of minor importance, but when they are associated with the wheat wireworm they add to the sum total of damage done to crops. The corn wireworms of the genus *Melanotus* are also known to inhabit the upland loam and sandy intervale soils of central Maine and cause extensive injury to corn similar to that done by the wheat wireworm. The wheat wireworm prefers relatively heavy loam soil which retains moisture. The group of wireworms of the genus *Ctenicera* is on occasion known to become relatively abundant in the heavier clay soils during years of wheat wireworm scarcity and to cause relatively heavy crop injury

FIGURE 11. The body of a feeding wireworm can be seen protruding from the bottom of the sprouted kernel of corn at right. Seed-corn decay and even total destruction of the seed may result from wireworm damage.

FIGURE 12. The roots and underground portions of stalks of corn are often damaged by feeding wireworms. Root systems of the three plants at the left in the top photo below are entirely destroyed.

FIGURE 13. The lower photo shows a stand of corn completely wiped out by wireworms. The insects move along from plant to plant during the growing season. There is a clear line between the infested field in the foreground and the clean field in the background where the corn is untouched.

under such conditions. Wireworms are seldom found in the Caribou loam soil of Aroostook county or in the well-drained, gravelly, or shale loam soils elsewhere in Maine. Good drainage reduces wireworm populations.

Sandy loam soils of the river valleys are the habitat of the eastern field wireworm, *Limonius agonus* (Say), and a closely related species, probably *Limonius plebejus* (Say). In this sandy habitat the corn wireworms are also sometimes sufficiently abundant to cause considerable crop injury.

Description of Life Stages of Wireworms

Larvae. When fully mature our destructive species of wireworms or elaterid larvae range in size from about 5/16-inch to 1-inch in length (fig. 14). The body is elongate and cylindrical in form, some species being slightly flattened on the underside of the body. Wireworms in general are protected by a hard and resistant outer skeleton, therefore they are aptly named "wireworms." Wireworms vary in color from pale yellow to mahogany brown according to species and state of moult.

Figure 14. Larvae of *Agriotes mancus* (Say) shown about life-size.

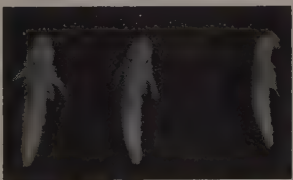

Figure 15. Pupae of *Agriotes mancus* enlarged to about twice their true size.

Pupae. When the wireworms are fully mature as larvae they make earthen cells and enter into a resting and reconstruction period called the pupal stage. As this happens, the wireworms gradually change in form and color into whitish pupae resembling less the form of the larva and more that of the beetle as the wings, legs, and beetle mouth parts develop (fig. 15). At the end of the pupal stage the adult elaterid beetle emerges.

FIGURE 16. Adults of *Agriotes mancus* shown about twice life-size.

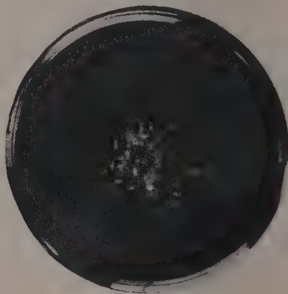

FIGURE 17. Eggs of *Agriotes mancus* in the bottom of a watch glass. The eggs shown are slightly reduced in size.

Adult. Beetles of our destructive wireworms range in size from about ¼-inch to about ⅝-inch in length (fig. 16). They are elongated, somewhat flattened, and are so constructed that they are able to spring into the air when placed in a prone position on their backs. The springing motion is accompanied by a clicking noise which has resulted in the adults often being called "click-beetles" or "skipjacks." These click-beetles, the adults of our common destructive wireworms, vary in color from light tan to dark brown. Adults of our injurious species are capable of sustained flight.

Eggs. The eggs from which wireworms hatch are scarcely visible to the eye without magnification (fig. 17). They are white in color when laid, gradually changing to a yellowish cream color before hatching. The individual eggs of our most destructive species, the wheat wireworm are spherical or oval in form, although they are flattened at their points of contact with each other and conform somewhat to the contour of particles of soil among which they are laid.

Life History and Habits of Wireworms

Knowledge of how and when wireworms attack plants forms a basis for their cultural and insecticidal control. The wheat wireworm has a life history of three years; that is, it takes three years for this species to complete the cycle from egg to adult, but a small number may carry over to the fourth year (fig. 18). Eggs laid in June or July of any year soon hatch into small cream colored wireworms only about 1.8 millimeters in length (fig. 19). These develop rapidly and pass the first winter as small, light-tan colored wireworms about ¼ to ⅜-inch in length. During the second year they grow very rapidly and feed voraciously causing much destruction when abundant. By the fall of the

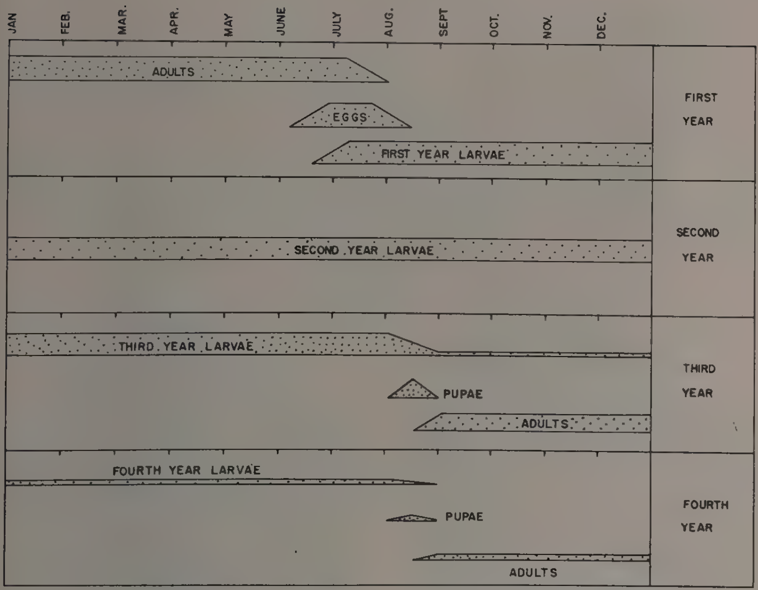

FIGURE 18. Life history chart of the wheat wireworm *Agriotes mancus* (Say).

second year the wheat wireworm is ½- to ⅝-inch in length, yellow in color, and the two dark brown eye-like spots on the last body segment are conspicuous. During the third year the wireworms feed heavily until about the middle of August when they enter their pupal cells and transform to beetles. The beetles emerge from the soil the following year and lay eggs which soon hatch and give rise to a new generation of wireworms. A few larvae of *Agriotes mancus* do not transform into beetles during the fall of the third year but live over to complete the cycle in the fourth year.

Some of our destructive wireworms have a life history similar to that of the wheat wireworm. Exceptions are the so-called corn wireworms of the genus *Melanotus* which are known to have a life history exceeding three years, and the abbreviated wireworm, *Hypolithus abbreviatus,* which has a life history extending over a single year. It is important to remember that when found as small wireworms some species may remain in the soil for a considerable portion of three years or even more unless they are controlled.

Natural Enemies of Wireworms

Thomas (1929) reported that a number of insects as well as some nematodes are parasitic on wireworms or on the adult beetles. Here in Maine nematodes or roundworms were found to be important parasites of the adult females of the wheat wireworm. These parasites almost filled the abdomens of the female beetles and no eggs were laid by the parasitized females kept under observation. The nematodes identified as *Hexamermis* sp. (fig. 20) were very abundant in 1930 and apparently were an important factor in reducing the number of wireworms.

FIGURE 19. Eggs laid in June or July hatch into small cream colored wireworms like these of *Agriotes mancus*. They are about 1.8 millimeters in length or about half the size shown.

FIGURE 20. A nematode, *Hexamermis* sp., is an important parasite of the wheat wireworm females. Other insects as well as toads, frogs, and birds also prey on the wireworm populations. Nematode above is life-size.

Predaceous insect enemies of wireworms are quite numerous. Staphylinids or rove beetles, carabids or ground beetles, and cicindelids or tiger beetles prey on either the larval or adult stages of wireworms. Birds such as bronzed grackles, our native sparrows, crows, and the imported starling consume both larval and adult wireworms, especially just after wireworm infested fields are plowed or harrowed. Toads and frogs are also known to consume the adult wireworm beetles (Thomas, 1931).

Cycles of Wireworm Abundance

Wireworm outbreaks follow when conditions in nature become favorable to their rapid propagation. When conditions become less favorable to rapid wireworm multiplication a period of relative wire-

worm scarcity will follow. Weather, parasites, and predators of wireworms all play complicated parts in the cycle of wireworm abundance.

Farm Practices to Control Wireworms

The growing of crops not favored as food by wireworms is a useful farm practice in their control. This is especially true when the crops chosen are cultivated annuals, because cultivation of the soil at regular intervals makes conditions unfavorable to the egg laying adults of the wheat wireworm and its associated species. Cultivation causes desiccation of very young larvae and eggs of wireworms by exposing them on the surface of the soil. Cultivation also destroys weeds and grasses which supply hiding places for the adults and food for the wireworm larvae. Cultivation effectively exposes all stages of the wireworms to their natural enemies. It should be emphasized, however, that unless cultivation is thorough enough to destroy witch grass (*Agropyron repens*), wireworms may breed in fields where crops of annuals are grown. Also, some of the wireworms living in cultivated areas become adults, leave the area, and deposit their eggs in soil seeded to grain or in soil which has not been cultivated recently.

Wireworm control by tillage. Data accumulated over a period of years consistently indicate that thorough cultivation is effective in controlling most species of wireworms. Some of these data are shown in the following table.

TABLE 3

Reduction in Wireworm Populations during Three Years of Cultivation (Fall Counts)

Plot No.	Population in thousands per acre		
	1931	1932	1933
1	120	92	19
2	170	73	17
3	225	178	63
4	212	127	15
5	532	107	20
6	416	88	18
7	329	133	18
8	246	95	11
9	93	35	5
10	43	29	8
11	132	114	111
12	253	124	19
13	467	148	112
14	273	103	23
15	151	165	51
16	162	119	78
17	48	25	40
Totals	3872	1755	628
Averages	228	103	37
Percentage decrease		55	84

Wireworm populations in the 17 plots from which the data for table 3 were taken averaged 228 thousand per acre at the beginning of the project in 1931 and only 37 thousand per acre at the end of the third year of cultivation, an approximate reduction of 84 per cent.

Additional data were obtained in 1950 and 1951 on the results of cultivation in reducing wireworm populations. The results are shown in table 4.

TABLE 4

Per Acre Populations of Wireworms in Cultivated Fields

Plot No.	Spring count (in thousands)	Fall count (in thousands)	Percentage reduction
1950			
1	256	155	39
2	72	13	82
3	258	152	41
1951			
1	185	70	62
2	224	83	63

This table shows wireworm populations at the beginning of the year before cultivation of the soil was started and at the end of the season after cultivation ceased. The wireworm reduction varied from 82 to 39 per cent of the spring population although cultivation was practically the same in all of the plots for the two years of this experiment.

The greater the population of wireworms to begin with, the more important it is to eliminate them quickly. For example, table 4 shows that 39 per cent of the population of 256,000 wireworms per acre was eliminated by cultivation during the year 1950; this left 155,000 wireworms per acre, a population capable of causing extensive injury to potatoes and other susceptible crops. In such cases insecticidal control is practical.

One section of a field used in wireworm investigations during 1950 was infested with witch grass while another section was relatively free of this weed. A study was made of the plots in order to obtain information on the abundance of witch grass in relation to reinfestation by first-year wireworms. The approximate division of the field into infested and cleanly cultivated portions and the total number of wireworms in each plot are indicated in figure 21. On the 20 grassy plots there was an average of 51,788 wireworms per acre. In comparison, on the clean plots there were 12,705 wireworms per acre. Wireworm populations on either a per acre or a per square foot basis are determined by counting the populations of soil samples 1 foot square and approximately 6 inches deep. These determinations will be referred to hereafter as wireworms per acre or per square foot without further reference to the

depth. The portion infested with witch grass was reinfested by about four times as many young wireworms as was the cleanly cultivated section.

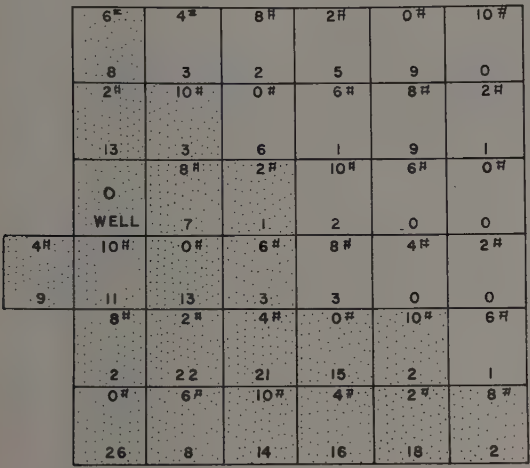

FIGURE 21. Diagrammatic map of a field showing the distribution of wireworm reinfestations, chlordane soil treatment dosages, and areas free of or infested with witch grass. Top numbers indicate pounds of chlordane per acre. Lower numbers show the count of first-year wireworms in 9 square feet of soil. Shaded area shows where witch grass was abundant.

Although factors other than the presence of witch grass are often important in influencing wireworm populations, in this field such factors were not of sufficient variation to account for the fourfold population increase where the witch grass was most abundant. General observations indicate that adults of certain injurious species seek the grassy areas for reproduction, and all evidence indicates that the presence of witch grass was the single most important factor in wireworm increase in these plots.

The conclusions drawn from the 1950 data verify conclusions from previous investigations which indicate that wireworm infestations are likely to continue in fields where potatoes are grown as long as witch grass continues to grow in any quantity.

Aside from its value in wireworm control, the elimination of witch grass is important not only because it absorbs moisture and nutrients needed for the crop but also because the witch grass rhizomes cause injury which is sometimes confused with that caused by wireworms. Deep witch grass injury (fig. 22) can usually be separated from wireworm injury because of the more regular path made by witch grass rhizomes in the tuber and by the fact that the resulting tunnel gradually tapers to a sharp point at the end of the rhizome. Figure 23 shows a less common type of witch grass injury in which the rhizome has grown entirely through the potato tuber.

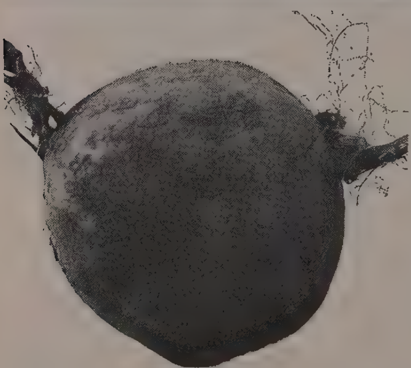

FIGURE 22. The six potatoes shown above are good examples of deep injury by witch grass, often mistaken for wireworm damage. Witch grass tunnels are usually more direct and they taper to a sharp point at the end of the rhizome.

FIGURE 23. A less common witch grass injury in which the rhizome has grown entirely through the potato.

Once wireworms are controlled by cultivation such fields will remain free until they are again reseeded to grass crops or are abandoned to weeds. Plowing when temperatures have become sufficiently low to inactivate the wireworms exposed by the plow causes the death of many. These inactive wireworms are easy prey to natural enemies.

Green manure crop. The use of annual green manure crops is a good practice in keeping wireworm populations from becoming excessive. Winter rye planted in late August or September and plowed down the following spring is an excellent crop for soil subject to wireworm

infestation. Clover is good when used as a green manure crop for soil infested by most species since they do not thrive on clover. With the exception of the genus *Limonius,* wireworms cannot exist in soil kept under clean culture. Strict adherence to that principle combined with short crop rotations and the omission of long-standing grass crops will permit potato culture where wireworms would otherwise destroy the crop.

Grain crop. Oats, wheat, barley, and rye are seldom greatly injured by wireworms although extremely high populations have on occasion caused injury to oats growing in wet portions of fields. Pure stands of clover are not ordinarily infested by wireworms, but if hay mixtures such as clover and timothy or clover and redtop are used wireworm populations may build up rapidly. Seeding grasses in oats or other spring grain seedings provide favorable conditions for wireworms especially where the seeding is not plowed up for several years. However, grain or grass crops which are sown broadcast or in drills often survive wireworm attack because of the great number of plants in a given area.

Effect of tillage on various species. A certain number of wireworms annually reach the adult stage and leave cultivated fields to lay eggs elsewhere. The number of wireworms remaining in the soil after a year of thorough cultivation depends to a considerable extent upon the age and species of the wireworms. The time required to reduce the wireworm population by thorough cultivation to a point where potatoes can be produced with safety is from 1 to 4 years depending upon the age, number, and species of wireworms present. Adults of the species *Limonius agonus,* the eastern field wireworm, and *L. plebejus* continue to lay eggs in cultivated fields indefinitely; consequently these two species of wireworms are not effectively controlled by cultivation. These two species are restricted to the well-drained soils of sandy intervale areas of Maine.

Taking a Wireworm Census

Occasionally growers of certain crops in Maine take a wireworm census as a precautionary measure before planting a crop in wireworm infested soil. Then the crop to be grown can be selected on the basis of probable freedom from wireworm injury or insecticide treatments may be employed.

Screening of the soil is one way of determining the number of wireworms present. In general, soil samples of about a square foot and to a depth of about 6 inches are dug up, sifted, and the wireworms are counted. Sufficient random samples are taken to make a representative sample. Representative samples should include soil from high, low, and

medium locations within the field. Census taking is facilitated when the operator can start sampling where the soil is relatively heavily infested, and then move outward sampling areas of lesser wireworm concentration. A sieve made by removing the bottom from a small crate or box and replacing the bottom with quarter-inch hardware cloth will serve as an aid in sifting the wireworms from the soil, or a round sieve may be purchased from local stores (cover photo). An engine-driven soil sifter containing screens of different mesh size has been devised for use in sampling wireworm populations over large areas (fig. 24). The wireworms are counted either as they pass through the first screen or are retained on the screens of the smaller sized mesh. The soil should be rather dry in order that it can be sifted effectively. The samples can be taken when the soil is moist, but they should be placed in containers from which the wireworms cannot escape and allowed to dry before sifting.

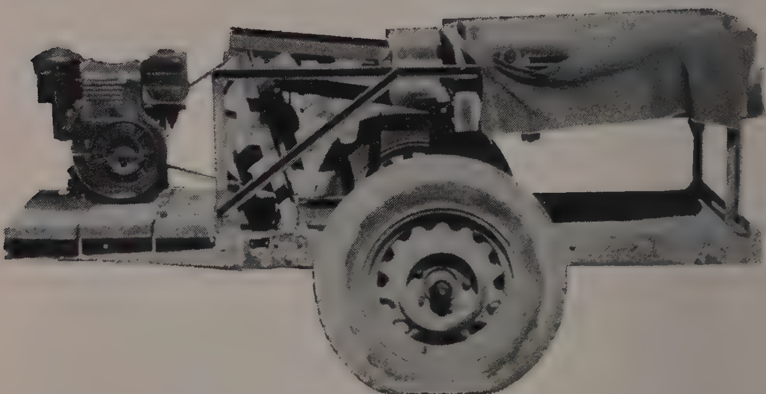

FIGURE 24. A power-driven soil sifter of this type is used in making a wireworm census over a large area. The wireworms are counted as they pass through the screen or when they are retained by a second screen of smaller mesh.

Baiting is an easy way to obtain a fairly accurate picture of the wireworm population, and it is quicker than the screening process. Baits consisting of 2 or 3 ounces of wheat or corn are buried to a depth of 3 or 4 inches in the soil. After they have had time to sprout, they can be dug up and examined for the number of wireworms present. The baits are located in representative areas in the fields as described in the preceding paragraph for soil sampling. Wheat and corn appear to be best for our common wireworms such as the wheat wireworm and the corn wireworms of the genus *Melanotus*. The eastern field wireworm

and near relatives are attracted to planted potato seed pieces.

Data obtained by making counts of wireworms found in soil samples or baits can be used to calculate the number of wireworms per acre and thus to determine the placement of a given crop where it has a chance to survive.

If an average of one or more wireworms is present per square foot of soil it is not considered safe to plant potatoes, a crop generally very susceptible to wireworm injury. A possible exception to this is in the sandy river valleys where wireworms of the genus *Limonius* are present since the principle injury by these larvae is to the seed only. Beans, peas, corn, and clover are very rarely injured extensively by wireworms in concentrations of 5 to 10 per square foot. However, the use of soil insecticides might be justified even with these low concentrations since damage to the seed has been known to occur to such crops as corn and peas. Rye, wheat, oats, and other grain crops are able to withstand the attack of many wireworms and can usually be grown where more than 10 wireworms per square foot are present. Although the figures presented here provide a general means of predicting whether or not it is safe to plant certain crops on land infested with wireworms, it should be understood that other factors including weather, age, and species of wireworms present may affect the degree of damage to a given crop. Therefore it is well to plan for a margin of safety when placing crops on infested soil, and if necessary insecticides should be employed for wireworm control.

Insecticidal Control of Wireworms on Potatoes

Wireworm control by the use of various materials was an objective of the research by Comstock and Slingerland in 1891. In Maine, Johannesen and Patch (1911) pioneered in the insecticidal control of wireworms. In 1926 another project in wireworm control was set up and various insecticides were included. The results of these experiments were published as Maine Agricultural Experiment Station Bulletin 381 (Hawkins, 1936). Calcium cyanide, which was used previous to 1936, was effective in wireworm control. Dichloroethyl-ether, calomel, and naphthalene showed promise but never proved practical in wireworm control (Hawkins, 1941).

The discovery of DDT and other related chlorinated hydrocarbon insecticides gave rise to an interest in these materials as wireworm insecticides. Greenwood (1947), Kulash (1947), and Pepper, Wilson, and Campbell (1947) showed that benzene hexachloride was toxic to wireworms. However, it was soon found to be associated with objectionable flavors in potatoes and its use was limited to other crops.

Rawlins, Staples, and Davis (1949) reported chlordane and heptachlor as effective insecticides for wireworm control on potatoes. Effective dosages indicated were 8 pounds per acre for chlordane and 4 pounds for heptachlor.

Along with heptachlor another insecticide, at first called Compound 118, was developed and later became known as aldrin. These insecticides were included in the preliminary experiments for insecticidal control of wireworms that were set up at Newport, Maine in 1950 by the Maine station.

Experiment 1 in 1950 and 1951 included only chlordane. A 5 per cent chlordane dust was applied to the surface and harrowed into the soil before planting. Effectiveness of the insecticide was evaluated in terms of percentage of tubers qualifying as grade U.S. No. 1, as is seen in the following table.

TABLE 5

Effect of Various Rates of Actual Chlordane Dust per Acre for Wireworm Control, 1950 and 1951

	Amount of actual chlordane dust per acre	Per cent of U.S. No. 1 tubers	
		1950	1951
1.	0	46	66
2.	2	47	—
3.	4	82	83
4.	6	93	86
5.	8	96	94
6.	10	97	95
7.	10*	—	84

The chlordane was applied prior to planting. A 6 x 6 latin square was used each year.

* Harrowing delayed 1½ hours.

Table 5 shows that chlordane dust used at a rate of 8 or 10 pounds of actual toxicant per acre was effective in preventing excessive wireworm damage to potato tubers. The 6-pound rate was somewhat less effective. Chlordane at a 2-pound rate was practically ineffective and the 4-pound rate would be impractical in most cases for wireworm control. There is a trend indicating that wireworm control increased as the amount of chlordane per acre was increased up to 10 pounds. Ten pounds of chlordane per acre is about the maximum application from the standpoint of crop contamination and economy. The degree of control obtained from the 10-pound rate of chlordane was considerably reduced when coverage of the latter was delayed until 1½ hours after distribution.

Experiment 2 of 1950 was established to obtain data on the amount of chlordane and the form in which it was applied in relation to the per-

centage of potato tubers qualifying as U.S. No. 1. Also included are data on aldrin and heptachlor used as wettable powder sprays.

TABLE 6

Comparison of Various Insecticides and Formulations for Wireworm Control Experiment 2—1950

Insecticide	Lbs. per acre (actual)	Per cent of U.S. No. 1 tubers
1. Chlordane dust	10	100.0
2. Chlordane spray—E*	10	100.0
3. Chlordane dust in fertilizer	10	98.0
4. Aldrin spray w.p.*	4	99.4
5. Heptachlor spray w.p.*	3	100.0
6. Control	0	85.3

Materials were applied prior to planting. The design was a 6 x 6 latin square.

* E = Emulsion and w.p. = wettable powder.

All materials listed in table 6 were applied to the soil and harrowed in before potatoes were planted, with the exception of the chlordane-fertilizer mixture which was applied in bands as the potatoes were being planted in the plots. Data contained in table 6 indicate that chlordane dust or spray applied at the 10-pound rate, aldrin at the 4-pound rate, and heptachlor at the 3-pound rate per acre were promising materials for wireworm control. When chlordane applied at the 10-pound rate per acre was combined with fertilizer, the resulting control was better than that obtained in the untreated soils, but was not quite equal to chlordane dust or spray not combined with fertilizer. The percentage of control obtained in all plots by cultivation was high, due at least in part to the fact that many of the wireworms became full grown and left the field as adults during July and August before doing much damage to the potatoes.

Many beetles of the family Carabidae, which contains many beneficial species, were killed in the field used for the second series of plots in 1950. It was difficult to ascertain which of the insecticides caused the death of the beetles due to the fact that they were found dead or dying in scattered sections of the area under treatment.

Experiment 2 of 1951 was organized to include eight treatments with eight plots for each treatment. Chlordane dust was used exclusively in the first three treatments listed in table 7.

Table 7 shows that 88 per cent of the tubers from treatment 1, in which 6 pounds of chlordane was combined with all the fertilizer used, were classified as U.S. No. 1, but only 82 per cent of the tubers were U.S. No. 1 in treatment 2 where 10 pounds of chlordane was used in a similar insecticide-fertilizer combination. This seeming inconsistency

TABLE 7

Comparison of Various Insecticides and Formulations for Wireworm Control
Experiment 2—1951

Insecticide	Lbs. per acre (actual)	No. of wireworms per acre		Per cent reduction of wireworms	Per cent of U.S. No. 1 tubers
		Spring	Autumn		
1. Chlordane in fertilizer	6	234,000	53,000	77	88
2. Chlordane in fertilizer	10	387,000	76,000	80	82
3. Chlordane dust	10	250,000	25,500	90	93
4. Chlordane spray	10	295,000	25,500	91	95
5. Chlordane spray	10	229,000	60,000	74	89
6. Aldrin spray	2	245,000	48,500	80	80
7. Heptachlor spray	2	234,000	36,000	85	86
8. Control	0	224,000	83,000	63	55

Materials were applied prior to planting. The design was an 8 x 8 latin square.

can be accounted for in part by the fact that there were approximately 155,000 more wireworms on a per acre basis in the plots of treatment 2 than there were in the plots of treatment 1 according to the early spring wireworm census.

In treatments 3 and 4 equal amounts of chlordane were applied as a dust or as a spray. Approximately 2 per cent better control was obtained with the spray. The number of wireworms (spring census) in plots receiving treatments 3 and 4 were essentially equal. Treatment 4, chlordane spray, was a little better than treatment 5 which was chlordane spray in which the chlordane was exposed until the potatoes were hoed several days after the chlordane was applied.

Aldrin spray and heptachlor spray applied at a rate of 2 pounds per acre were not quite equal to the chlordane dust or spray applications (treatments 3 and 4). The chlordane-fertilizer combinations of 6 and 10 pounds of chlordane, respectively, were not quite equal to the chlordane at the 10-pound rate when used as dust or spray alone, as judged on the basis of percentage of U.S. No. 1 tubers produced.

Experiment 1 of 1952 included aldrin, chlordane, dieldrin, and Systox as the insecticides used. The plots were set up to include the five treatments and a control, each replicated six times. The soil was sampled for the wireworm population previous to planting the potatoes. The data obtained are included in the following table.

In terms of increase in percentage of U.S. No. 1 potatoes over the control plots, treatments of chlordane, dieldrin, and aldrin emulsions produced the most effective results. The wireworm populations were much higher in the Systox plots prior to treatment, which would at least have a tendency to show the other insecticides to advantage.

Experiment 2 of 1952 was designed to study the effect of insecticides on wireworm injury to potato plants. Twenty plants from each of the 49 plots of this experiment were inspected for wireworm damage to

TABLE 8

Comparison of Various Insecticides and Formulations for Wireworm Control
Experiment 1—1952

Insecticide	Lbs. per acre (actual)	No. wireworms per acre before treatment	Per cent of U.S. No. 1 tubers
1. Chlordane dust	10	40,750	87
2. Chlordane emulsion	10	20,375	98
3. Aldrin emulsion	3	20,375	96
4. Dieldrin emulsion	3	47,270	98
5. Systox emulsion	2½	733,500	65
6. Control	0	713,000	44

Materials were applied prior to planting. The design was a 6 x 6 latin square.

the potato vines and root systems. This was accomplished by carefully removing the soil around the plant and seed piece and examining the underground portion of the plant. Plants showing excessive damage were removed from the field and brought into the laboratory for closer examination. Data obtained are shown in the following table.

TABLE 9

Comparison of Various Insecticides and Formulations for Preventing Damage to Potato Plants
Experiment 2—1952

Treatment	Lbs. per acre (actual)	Per cent damage to plants (estimated)
1. Systox	2½	5
2. Chlordane spray	10	0
3. Chlordane dust	10	10
4. Aldrin	3	5
5. Dieldrin	3	0
6. Dowfume W-85	16	0
7. Control	0	60

The materials were applied prior to planting. The design was a 7 x 7 latin square.

Excellent protection was afforded in all treated plots with slight damage noted in the chlordane dust plots. Tubers in the plots in which the plants showed only 5 per cent damage probably would not suffer serious injury.

A factor that should be considered is the extremely dry condition that prevailed throughout the month of July. No rain was recorded for 28 days at the farm where the 1952 experiments were conducted.

Experiments 1 and 2 of 1953 were designed to evaluate emulsion sprays and broadcast granular applications of two different rates of aldrin and chlordane. The data in table 10 are self explanatory and show that all of the materials and formulations provided good control

of wireworms. It appears that the granular applications are about as effective as the emulsion spray applications.

TABLE 10

Comparison of Emulsion Sprays and Broadcast Granular Forms of Aldrin and Chlordane for Wireworm Control—1953

Treatment	Lbs. per acre (actual)	Per cent of U.S. No. 1 tubers	
		Experiment 1 Emulsion spray	Experiment 2 Granular broadcast
1. Aldrin	3	97.2	89.8
2. Aldrin	2½	97.4	90.8
2. Chlordane	10	96.4	97.6
4. Chlordane	8	96.6	94.6
5. Control	0	43.0	53.4
L.S.D. 5% level of significance		15.6	9.0

The materials were applied to the surface of the soil and immediately harrowed into the soil. Each experiment consisted of a 5 x 5 latin square.

Experiment 3 of 1953 was designed primarily to study the effect of nine different insecticide formulations in relation to wireworm injury to potato tubers. Results are interpreted in percentages of tubers attaining U.S. No. 1 grade (table 11). The insecticides are listed in order of their effectiveness.

TABLE 11

Comparison of Various Insecticides and Formulations for Wireworm Control Experiment 3—1953

Treatment	Lbs. per acre (actual)	Form	Application method	Per cent of U.S. No. 1 tubers
1. Heptachlor	3	25% emulsion	Surface spray	98.8
2. Chlordane	10	75% "	" "	98.2
3. Heptachlor	2½	25% "	" "	96.0
4. Chlordane	10	50% wettable powder	" "	95.2
5. Parathion	10	25% emulsion	" "	95.2
6. Heptachlor	3	5% granular	Broadcast on surface	91.0
7. DDT	10	50% wettable powder	Surface spray	89.2
8. Endrin	3	19% emulsion	" "	88.8
9. Chlordane	10	10% granular	In fertilizer	64.6
10. Control	0			48.2
L.S.D. 5% level of significance				9.52

The materials were applied prior to planting. The design was a 10 x 10 latin square.

Table 11 shows all insecticides used in these experiments to be significant in producing potato tubers of grade U.S. No. 1. The poor showing of chlordane in granular form cannot be accounted for in the light of previous experience. Although granular chlordane did not perform well, the percentage of U.S. No. 1 tubers was considerably greater than that produced by the control plots. All the insecticides except the granular-chlordane-fertilizer mixture were applied to the surface and harrowed into the soil. The chlordane-fertilizer mixture was applied in

bands with the potato planter. The materials used in 1953 all showed considerable promise as wireworm insecticides.

Potatoes planted in 1954 were irregular in growth because of excessive soil moisture. Some of the plots even had too few plants to be considered. There was also considerable rotting of the tubers during the fall months so that the data taken on the relation of the insecticides to the percentage of U.S. No. 1 potato tubers were not reliable.

TABLE 12

Comparison of Various Materials for Wireworm Control
Experiment 1—1955

Treatment	Lbs. per acre (actual)	Per cent of U.S. No. 1 tubers
1. Heptachlor	2½	100.00
2. Chlordane	8	98.4
3. Dieldrin	2½	98.0
4. Aldrin	2½	97.4
5. DDT	10	78.4
6. Magnesium sulfate	28	54.4
7. Control	0	79.7
L.S.D. at 5% level		.93
at 1% level		1.25

The materials were applied prior to planting. The design was a 7 x 7 latin square.

Table 12 includes data on potatoes grown in plots in experiment 1 during 1955. This experiment included five effective insecticides and magnesium sulfate. Three hundred tubers from each treatment were examined for injury. Aldrin, chlordane, DDT, and dieldrin were applied as emulsions in water and the magnesium sulfate as crystalline powder. The materials were raked into the soil upon application.

In this experiment heptachlor, chlordane, dieldrin, and aldrin were effective in preventing wireworms from causing excessive injury to potato tubers. Where magnesium sulfate was used, there was an in-

TABLE 13

Comparison of Various Insecticides for Wireworm Control
Experiment 2—1955

Treatment	Lbs. per acre (actual)	Per cent of U.S. No. 1 tubers
1. Aldrin	2½	100.0
2. Heptachlor	2½	97.0
3. Chlordane	8	96.4
4. Dieldrin	2½	96.4
5. DDT	10	82.0
6. Control	0	61.0
L.S.D. at 5% level		1.25
at 1% level		1.68

The materials were applied prior to planting. The design was a 6 x 6 latin square.

creased amount of injury to potato tubers. The DDT treatments produced slightly inferior results as compared to the control plots.

Table 13 includes data on potatoes grown in experiment 2 of 1955. Three hundred tubers were examined for wireworm injury from each of the treated and control plots with the exception of the plots treated with chlordane where but 240 tubers were obtainable. The materials used in this experiment were applied in the same form and amounts as in experiment 1, 1955.

All of the soil insecticides used in experiment 2 were effective in preventing excessive injury to potato tubers. Here aldrin produced 100 per cent U.S. No. 1 tubers. Heptachlor, dieldrin, and chlordane also produced excellent wireworm control.

It is unusual that aldrin used in experiment 2 and heptachlor used in experiment 1 resulted in complete control of wireworms. Only rarely is such a high degree of control accomplished. In experiment 1 none of the potatoes grown in the heptachlor plots were out of grade U.S. No. 1 because of wireworm injury, and only 2.6 per cent of the potatoes harvested from the aldrin plots were thrown out of U.S. No. 1 grade. In experiment 2 none of the potatoes grown in the aldrin treated plots were out of U.S. No. 1 grade, and only 3 per cent of the potatoes grown in the heptachlor plots were out of grade.

The 1955 data support previous results showing that aldrin and heptachlor are excellent soil insecticides for use in controlling wireworms. It is also to be noted that dieldrin and chlordane greatly restricted the amount of injury caused to potato tubers by wireworms. However, DDT used at a rate of 10 pounds per acre during 1955 provided no discernible control in experiment 1 and was less effective than other insecticides used in experiment 2.

Magnesium sulfate did not prove to be practicable in wireworm control as is shown in table 12, although previous laboratory studies had shown magnesium sulfate to be toxic to wireworms.

In 1956 the insecticides applied to the soil consisted of aldrin, chlordane, and heptachlor. Each material was applied in emulsion form and raked into the soil previous to planting or in granular form mixed with fertilizer and applied at the time of planting. The plots used consisted of two rows, each 40 feet in length, and three feet apart. Each plot contained 240 square feet or approximately 1/181 of an acre.

At the time of harvest 48 tubers were chosen at random from each separate replication and were examined for wireworm injury. The potatoes were judged on the basis of those tubers which were sufficiently free from wireworm injury to qualify as U.S. No. 1 grade. The results are shown in table 14.

TABLE 14

Comparison of Fertilizer Mixtures and Emulsion Sprays for Wireworm Control
Experiment 1—1956

Treatment	Lbs. per acre (actual)	Per cent of U.S. No. 1 tubers
1. Heptachlor emulsion	2½	97.0
2. Chlordane emulsion	8	96.5
3. Aldrin emulsion	2½	91.9
4. Heptachlor-fertilizer	2½	88.4
5. Chlordane-fertilizer	8	87.2
6. Aldrin-fertilizer	2½	79.2
7. Control	0	83.2
L.S.D. at 5% level		4.67
at 1% level		6.29

The materials were applied prior to planting. The design was a 7 x 7 latin square.

This experiment adds support to prior observations which indicated that insecticide-fertilizer mixtures generally do not perform as well as when the insecticide is mixed directly with the soil. However, 1956 was a particularly poor growing season, and excessive moisture was present in some of the plots soon after planting. Consequently, the stand of potato plants was uneven.

The 1957 experiment in insecticidal control of wireworms included five treatments and a control. There were six replications of each or 36 plots. The insecticides were applied in the form of emulsions and then were raked into the soil after which the potatoes were planted and slightly hilled. The rows were later ridged by cultivation as is the usual procedure in growing potatoes in Maine. Heptachlor, dieldrin, aldrin, and chlordane were the insecticides. The potato plants were sprayed sufficiently to control insects and diseases. At harvest on October 9, 60 tubers of approximately uniform size were chosen at random from each plot and later graded on the basis of the number of tubers from each plot and treatment which were sufficiently free from wireworm

TABLE 15

Comparison of Various Insecticides for Wireworm Control
Experiment 1—1957

Treatment	Lbs. per acre (actual)	Per cent of U.S. No. 1 tubers
1. Heptachlor	2½	95.9
2. Dieldrin	2½	95.6
3. Aldrin	2½	95.0
4. Chlordane	5	95.0
5. Chlordane	8	94.5
6. Control	0	60.3
L.S.D. at 5% level		5.1
at 1% level		8.0

The materials were applied prior to planting. The design was a 6 x 6 latin square.

injury to qualify as U.S. No. 1 grade. Results of the 1957 experiment are recorded in table 15.

The results of the 1957 experiments in general confirmed data from previous trials. Aldrin, chlordane, dieldrin, and heptachlor are effective insecticides for the control of wireworms. However, the results obtained from the use of five pounds of chlordane per acre were equal to or even better than chlordane used at the 8-pound rate per acre. This seeming inconsistency cannot be accounted for.

Effect of Soil-Applied Insecticides on the Flavor of Potatoes

Taste-panel studies were made in 1953, 1954, and 1955 to determine whether or not the flavor of cooked potatoes was affected by some of the insecticides.

Although the treatments are described in various sections of this bulletin, they are recapitulated here to relate them more closely to the flavor studies (table 16). The insecticides were sprayed on the soil before planting and were raked in by hand. Each year the plots were planted on soil which had no history of previous soil insecticide treatment. All of the insecticides used were at levels recommended for wireworm control in this area.

Samples: The test in 1953 was considered preliminary since the samples were less uniform than desirable and storage conditions were not ideal. Six tubers were chosen at random from the composited field replications to constitute a taste sample.

The 1954 and 1955 samples were graded for size (between 5.0 and 6.6 ounces). Each composite sample consisted of one tuber taken from each of the field replications, five in 1954 and seven in 1955.

The tubers were baked at 425° F. until tender, then mashed and mixed before serving.

The samples were tested by a ranking method in balanced incomplete block designs (Cochran and Cox, 1950), three at a time in 1953 and 1954, and four at a time in 1955.

The panels consisted of experienced judges: 19 in 1953, 40 in 1954, and 47 in 1955. They judged the samples for flavor only and indicated whether or not the samples were acceptable.

Results: The ranks were transformed to scores according to Fisher and Yates (1948) for normalizing ranked data. Variance analyses of the combined judge scores (table 17) showed that no significance was attached to treatments in any of the three years. In addition, analyses showed that all of the potatoes grown on insecticide-treated soils were as acceptable as those from the untreated plots.

TABLE 16

Data Applying to Flavor Samples

Treatment (Emulsion concentrate)	1953 Kennebec lbs./acre (actual)	1954 Green Mountain lbs./acre (actual)	1955 Green Mountain lbs./acre (actual)
Untreated	0	0	0
Aldrin	2.5	2.5	2.5
Aldrin	3.0	—	—
Chlordane	8.0	8.0	8.0
Chlordane	10.0	—	—
Heptachlor	—	2.5	2.5
DDT	—	10.0	10.0
Dieldrin	—	—	2.5
Mg SO_4	—	—	28.0
Date applied	June 17	June 18	May 24
Location	Glenburn, Maine	Highmoor Farm	Highmoor Farm
Planting designs	5 x 5 latin square	5 x 5 latin square	7 x 7 latin square
Soil types	Clay	Charlton loam pH 6.4	Charlton loam pH 6.4
Fertilizer	8-16-16 at 600 lbs./a	8-16-16-2 at 1400 lbs./a	Same as 1954
Fungicide		5 lbs. neutral copper 5 lbs. hydrated lime 1 lb. DDT per 100 gal. weekly for 14 weeks	Same as 1954
Planting dates	June 19	June 18	May 24
Harvest dates	October 16	October 20	October 23
Av. temp. June 1-Sept. 30	No record	58.76° F.	67.0° F.
Total rain fall June 1-Sept. 30	No record	23.79 inches	14.10 inches
Storage conditions	Room temperature until tested (7 weeks)	65° F. until October 28	68° F. until October 26
Dates of taste test	December 10-12	October 28-November 1	October 26-27

TABLE 17

Palatability Scores Assigned to Baked Kennebec and Green Mountain Potatoes Grown on Insecticide-Treated Soils

Test 1 December 1953 Kennebec			Test 2 October 1954 Green Mountain			Test 3 October 1955 Green Mountain		
Treatment	lbs. per acre	Total scores[1] 19 judges	Treatment	lbs. per acre	Total scores[1] 40 judges	Treatment	lbs. per acre	Total scores[1] 47 judges
Chlordane	8.0	+12.75	DDT	10.0	+21.25	Heptachlor	2.5	+23.26
Chlordane	10.0	+ 5.10	Aldrin	2.5	+ 7.65	Chlordane	8.0	+ 8.11
Untreated		− 3.40	Heptachlor	2.5	− 5.10	Dieldrin	2.5	+ 6.52
Aldrin	2.5	− 5.95	Chlordane	8.0	−11.90	DDT	10.0	+ 5.66
Aldrin	3.0	− 8.50	Untreated		−11.90	Untreated		− 6.91
						Aldrin	2.5	− 8.24
						$MgSO_4$	28.0	−28.40
		Not significant			Not significant			Not significant

Analyses of Variance Tables

Source	D.F.	M.Sq.	F	D.F.	M.Sq.	F	D.F.	M.Sq.	F
Total	569			1199			1315		
Treatment	4	0.68	0.94	4	0.85	1.47	6	1.42	1.97
Judge	18	0	—	39	0	—	46	0	—
Treat. x Judge (error for treat.)	72	0.72	1.57	156	0.58	1.21	276	0.72	1.29*
Error	475	0.46		1000	0.48		987	0.56	

[1] Ranks transformed to scores (Fisher and Yates, 1948). High scores indicate high preference.

* Significant at the 5% level.

Application of Soil Insecticides for Wireworm Control

Applications of soil insecticides are often made with several types of machines. In large fields lime and fertilizer spreaders are used for distributing dusts and granular types of insecticides. In some cases dusts are applied with a power-driven duster. Power-driven sprayers are also used for applying emulsifiable and wettable powder insecticides.

In the small experimental plots a small fertilizer spreader was used for the application of dust and granular insecticides or insecticide-fertilizer combinations. Insecticide-fertilizer combinations were also applied in bands on either side of the planted potato seed by the fertilizer attachment of a potato planter. Hand-operated sprayers and garden sprinklers were also used in applying liquid insecticides to the soil.

Regardless of the type of machinery used to distribute insecticides, it is important that they be applied to the surface as evenly as possible in order to prevent excessive amounts of objectionable residue. Careful measuring of exact amounts and careful calibration of the machinery used, are necessary for economic and efficient insecticidal control of wireworms.

Immediate coverage of insecticides greatly enhances the control of wireworms. This may be accomplished by harrowing or raking the insecticide into the soil or by covering it by means of a potato hiller as soon as possible after application.

The economics of applying insecticides to the soil for wireworm control depends upon many factors. Some of these are the number of wireworms present in the soil, the kind of crop to be grown, the value of the crop, the species of wireworms present, the age of the wireworms, the cost of the insecticide, and the type of soil under cultivation.

Data on the economics of the use of insecticides for the control of wireworms attacking potatoes for the years 1950 through 1952 are shown in table 18.

TABLE 18

Economics of Applying Insecticides to Infested Potato Fields for Wireworm Control—1950-52[1]

Year	Bushels of tubers per acre (U.S. No. 1)			Price per bushel	Increased return per acre if treated	Average per acre	
	Treated plots	Check plots	Increase due to treatment			Cost of treatment*	Profit from treatment
1950	477.5	404.6	72.9	$1.00	$72.90	$14.07	$58.83
1951	384.5	244.8	139.7	1.81	252.85	10.76	242.09
1952	319.7	158.4	161.3	1.35	217.75	14.60	203.15

[1] Average infestation for four years 271,550 wireworms per acre, mostly *Agriotes mancus* (Say). Potato prices based on U.S.D.A. Maine averages.

* Also cost of application must be considered, i.e., cost of applying insecticide to one acre and cost of harrowing one acre once.

The figures for these three years indicate that treatments may increase considerably the yields and profits. However, the market value of the crop is of great importance since profits are greater when the market value of a crop is high. The cost of application was less than \$15 per acre. Net returns varied from about \$59 per acre in 1950 to \$242 in 1951.

Soil Fumigation for Wireworm Control

Soil fumigation offers a possible alternative to the use of soil insecticides. This method has proved successful in other sections of the country, particularly in the southern states and along the west coast. For this reason several experiments were conducted with ethylene dibromide in order to determine the performance of this soil fumigant in Maine.

The chief advantage of fumigation is that good control may be obtained without the danger of long lasting residues in the soil. There are factors which make fumigation difficult in Maine, but they do not render it impossible. The high material cost may be prohibitive unless a high-cash-per-acre crop such as potatoes or market garden produce is to be protected. Soil temperatures above 60° F. are necessary in order that the material may volatilize readily. Unfortunately, this temperature is seldom reached in Maine soils before midsummer.

LIST OF MAINE ELATERIDAE (Beetles)

1. *Lacon brevicornis* (Lec.)
2. *Lacon obtecta* (Say)
3. *Alaus oculatus* (Linn.)
4. *Pityobius anguinus* Lec.
5. *Limonius plebejus* (Say)
6. *Limonius agonus* (Say)
7. *Athous brightwelli* (Kby.)
8. *Denticollis denticornis* (Kby.)
9. *Ctenicera kendalli* (Kby.)
10. *Ctenicera vernalis* (Hentz)
11. *Ctenicera resplendens* (Esch.)
12. *Ctenicera sjaelandica* (Müller)
13. *Ctenicera cylindriformis* (Hbst.)
14. *Ctenicera appressa* (Rand.)
15. *Ctenicera caricina caricina* (Germ.)
16. *Ctenicera caricina tarsalis* (Melsh.)
17. *Ctenicera spinosa* (Lec.)
18. *Ctenicera insidiosa* (Lec.)
19. *Ctenicera hamata* (Say)
20. *Ctenicera triundulata* (Rand.)
21. *Ctenicera mediana* (Germ.)
22. *Ctenicera aeripennis* (Kby.)
23. *Ctenicera nigricornis* Panz.
24. *Ctenicera arata* (Lec.)
25. *Ctenicera cruciata* (Linn.)
26. *Ctenicera hieroglyphica* (Say)
27. *Hemicrepidius decoloratus* (Say)
28. *Hemicrepidius memnonius* (Hbst.)
29. *Hypolithus abbreviatus* (Say)
30. *Negastrius tumescens* (Lec.)
31. *Oestodes tenuicollis* (Rand.)
32. *Dalopius lateralis* Mann.
33. *Agriotes mancus* (Say)
34. *Agriotes ferrugineipennis* (Lec.)
35. *Agriotes pubescens* Melsh.
36. *Agriotes limosus* (Lec.)
37. *Agriotella bigeminata* (Rand.)
38. *Ampedus pullus* Germ.
39. *Ampedus semicinctus* (Rand.)
40. *Ampedus rubricus* (Say)
41. *Ampedus apicatus* (Say)
42. *Ampedus mixtus* (Hbst.)
43. *Ampedus nigricans* Germ.
44. *Melanotus castanipes* (Payk.)
45. *Melanotus leonardi* (Lec.)
46. *Melanotus fissilis* (Say)
47. *Melanotus pertinax* (Say)
48. *Cardiophorus gagates* Er.
49. *Cardiophorus convexulus* Lec.
50. *Cardiophorus filius* Rand.
51. *Cardiophorus dispar* Bl.

Food Plants of Elaterid Larvae in Maine

CAMPANULACEAE

1. Balloon-flower. *Platycodon grandiflorum* A.DC.

CARYOPHYLLACEAE

2. *Gypsophila* spp.

CHENOPODIACEAE

3. Beet. *Beta vulgaris* L.
4. Spinach. *Spinacia oleracea* L.

COMPOSITAE

5. Aster. *Aster* spp.
6. Endive. *Cichorium Endivia* L.
7. Dahlia. *Dahlia* spp.
8. Blanket-flower. *Gaillardia* spp.
9. Common Dandelion. *Taraxacum officinale* L.

CRUCIFERAE

10. Charlock. *Brassica Kaber* (DC.) L. C. Wheeler var. *pinnatifida* (Stokes) L. C. Wheeler
11. Wild Rutabaga. *Brassica Rapa* L.
12. Rutabaga. *Brassica Napobrassica* Mill.
13. Cauliflower. *Brassica oleracea* L. var. *botrytis* L.

14. Cabbage. *Brassica oleracea* L. var. *capitata* L.
15. Wild Radish. *Raphanus Raphanistrum* L.
16. Cultivated Radish. *Raphanus sativus* L.

CUCURBITACEAE

17. Muskmelon (fruit). *Cucumis Melo* L.
18. Cucumber. *Cucumis sativus* L.
19. Winter Squash (roots and fruit). *Cucurbita maxima* Duchesne.
20. Pumpkin (fruit). *Cucurbita Pepo* L.

GRAMINEAE

21. Quack, Witch, Quitch or Couch grass. *Agropyron repens* (L.) Beauv.
22. Redtop. *Agrostis alba* L.
23. Foxtail Grass. *Alopecurus* spp.
24. Oat. *Avena sativa* L.
25. Barnyard Grass. *Echinochloa crusgalli* (L.) Beauv.
26. Barley. *Hordeum vulgare* L.
27. Timothy. *Phleum pratense* L.
28. Rye. *Secale cereale* L.
29. Wheat. *Triticum aestivum* L.
30. Corn. *Zea Mays* L.

LEGUMINOSAE

31. Cultivated Lupine. *Lupinus* spp.
32. Bush Lima Bean. *Phaseolus limensis* L. and *P. lunatus* L.
33. Common Bean. *Phaseolus vulgaris* L.
34. Garden Pea. *Pisum sativum* L.
35. Alsike Clover. *Trifolium hybridum* L.
36. Red Clover (stem on soil). *Trifolium pratense* L.
37. Vetch (seed in the soil). *Vicia* spp.

LILIACEAE

38. Onion. *Allium Cepa* L.

PINACEAE

39. White Pine (logs; beneath bark). *Pinus Strobus* L.

PLANTAGINACEAE

40. Common Plantain. *Plantago major* L.

POLEMONIACEAE

41. Cultivated Phlox. *Phlox* spp.

POLYGONACEAE

42. Common Buckwheat. *Fagopyrum sagittatum* Gilib.

RANUNCULACEAE

43. Cultivated Columbine. *Aquilegia* spp.

ROSACEAE

44. Strawberry. *Fragaria* spp.
45. Apple (fruit on ground and beneath bark of tree). *Pyrus Malus* L.

SOLANACEAE

46. Tomato. *Lycopersicum esculentum* Mill.
47. Eggplant. *Solanum Melongena* L.
48. Potato. *Solanum tuberosum* L.

UMBELLIFERAE

49. Cultivated Carrot. *Daucus Carota* L. var. *sativa* DC.

The scientific names were checked by Dr. C. D. Richards, Department of Botany, University of Maine.

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